

# Intra-operative DynaCT improves technical success of endovascular repair of abdominal aortic aneurysms

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**Objectives:** To evaluate feasibility, technical success, and the need for reintervention in the early perioperative period, following the introduction of intraoperative DynaCT (DynaCT, Siemens AG, Berlin, Germany) in patients undergoing infrarenal endovascular aneurysm repair (EVAR). DynaCT involves the generation of computed tomography (CT)-like images from “on table” rotational angiographic acquisition.

**Methods:** A prospectively maintained database of 312 patients undergoing EVAR (September 2001 - February 2007) was interrogated to determine incidence of early reintervention following satisfactory appearances of uniplanar completion angiography (control group). Following the introduction of DynaCT (DynaCT group - 80 patients), clinical and radiologic outcomes were prospectively evaluated (September 2007 - May 2008). Both groups underwent pre-discharge computed tomographic angiography (CTA) and color-flow duplex scan. Comparative analysis of procedural data, hospital-stay, mortality, and early reintervention between the two groups was undertaken.

**Results:** In the control group, 14 (4.5%) patients required reintervention procedures within 30 days of EVAR (10 endovascular, 7 surgical). Six patients had type 1 endoleaks and 8 presented with acute limb ischemia. Review of this cohort suggested that the majority of complications (86%) may have been immediately identifiable with improved intra-operative quality control. In the DynaCT group, DynaCT was feasible in 81.3% ( $n = 65/80$ ) of patients and resulted in the detection of five clinically significant anomalies (6.25%,  $n = 5/80$ ). These technical problems were not identified at completion angiography but were corrected after DynaCT (2 type 1 endoleaks, 1 type 3 endoleak, 1 limb compression, and 1 graft thrombosis). Standard pre-discharge imaging did not identify any further graft-related complications in the DynaCT group. Introduction of DynaCT resulted in a reduced need for early reintervention (0/80 vs 14/312,  $P = .05$ ).

**Conclusion:** Most graft-related complications that mandate early reintervention following EVAR are due to remediable technical problems which are not identified by uniplanar completion angiography alone. DynaCT is a feasible intra-operative adjunct to completion angiography, which improves intra-operative quality control during endovascular repair of abdominal aortic aneurysms. (*J Vasc Surg* 2009;49:288-95.)

Endovascular repair (EVR) of abdominal aortic aneurysms (AAA) is associated with a reduced risk of perioperative death when compared to open aneurysmorrhaphy in randomized controlled trials, but has been associated with a higher incidence of surgical and endovascular reintervention.<sup>1</sup> In randomized trials, early reintervention following EVR of AAA was required in up to 10% of patients at 30 days.<sup>2</sup> The most common indications for reintervention were type I endoleaks, stent migration, and graft limb thrombosis. These preventable technical problems that require early reintervention have significant cost implications as well as having adverse consequences for the patient.

The requirement for early revisional procedures has been demonstrated to be associated with an increased risk

of mortality (7.5%-8%)<sup>3,4</sup> for endovascular aortic repair. Most conditions that mandate early revision are due to remediable technical problems that have not been identified or rectified during the primary procedure. At present, many endovascular surgeons use uniplanar angiography to assess the technical efficacy of the primary endovascular repair. However, from the early revisional rates it would appear that satisfactory uniplanar completion angiography in isolation is insufficient to detect all graft-related anomalies. The majority of early technical problems requiring reintervention are detected by duplex scanning or cross-sectional imaging performed in the interval between the termination of the endovascular procedure and patient discharge.<sup>5,6,7</sup>

Improving intra-operative quality control during endovascular repair of AAAs is crucial to reduce early reintervention, improve cost effectiveness, and reduce perioperative mortality/morbidity. Ideally, any method of quality control must be available during the endovascular procedure, and would be able to effectively assess the position of the endograft; determine the perfusion of visceral branches; demonstrate the presence of endoleaks; define any problems with the iliac limbs, and suggest a revisional strategy.

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The intra-operative gold standard for quality assurance following endovascular aneurysm repair (EVAR) is yet to be determined with some centers advocating the use of biplanar angiography, intra-vascular ultrasound scan, wireless pressure transducers, or CO<sub>2</sub> angiography to reduce the incidence of technical failure.<sup>8-10</sup>

The present study investigates the use of on-table angiographic computed tomography (DynaCT, Siemens Medical, Berlin, Germany) as a method of quality control during endovascular abdominal aneurysm repair.

## METHODS

**Study Design.** The prospectively maintained database was interrogated to determine the incidence of early reintervention in patients undergoing endovascular aneurysm repair of infrarenal aneurysms (control group). After this review had been completed, an investigation into the use of intra-operative DynaCT in a prospective cohort of 80 patients was instigated (DynaCT group). The change in assessment protocol was approved by the New and Novel Procedures Committee of our Institution, and involved the performance of a DynaCT after uniplanar completion angiography was deemed satisfactory. The endpoints of the study were the technical success of the DynaCT examination, the number of technical problems identified by DynaCT after satisfactory completion of angiography, and the subsequent number of early reinterventions in the perioperative period. The findings of completion angiography and DynaCT were independently assessed by an observer blinded to procedural outcome.

**Early reintervention rate in the control group.** A prospectively maintained database from 312 consecutive patients undergoing EVR from September 2001 - September 2007 was interrogated to define the early reintervention rate in patients undergoing EVR with satisfactory uniplanar completion angiography. For the purposes of the present investigation, the patients in this cohort were termed the control group. Early reintervention was defined as a secondary surgical or endovascular procedure that occurred within 30 days of the primary endovascular aneurysm repair or during the primary hospital episode.

**Quality assessment protocol in the control group.** All patients in the control group (prior to September 2007) underwent a standard procedure for quality control after deployment of the aortic endoprosthesis. Quality control during infrarenal EVR relied upon uniplanar angiography in the anterior/posterior (AP) projection to assess the technical success of the endovascular repair. Prior to angiography, all stiff wires were removed and a pigtail catheter was positioned above the level of the renal arteries. Intra-arterial digital subtraction angiography (DSA) was then performed using 20 mL of full strength contrast injected at 10 mL/second. The endograft was assessed for position, integrity, flow through the graft, patency of the renal arteries, presence of endoleak, and configuration of the iliac limbs. If any technical problems were identified, these were corrected, and completion angiography repeated. This se-

quence was followed until technical success was achieved or further revisional procedures were deemed inappropriate.

Following recovery from the procedure, patients underwent duplex ultrasound scan and computerized tomography assessment of the endovascular repair prior to discharge. In most cases, this assessment took place the day after EVR. Any technical defects were identified and recorded. The strategy for correction of any technical problems depended on the fitness of the patient and the magnitude of the problem. As a general principle, all patients with type I or III endoleaks were considered for urgent revision on the same admission, and patients with graft limb problems according to clinical need.

**Change in quality assessment protocol (September 2007) – DynaCT.** In September 2007, the intra-operative quality control protocol for assessment of infrarenal EVR was changed. The only change to endograft deployment was an attempt to reduce contrast load by using, where feasible, CO<sub>2</sub> angiography in the initial positioning of the endograft and demonstration of the iliac bifurcation. Quality control was performed as detailed above, with completion angiography guiding initial adjunctive procedures. When completion angiography was deemed satisfactory by the operating surgeon, patients underwent DynaCT as described below.

Exclusion criteria from the protocol were as follows:

- preoperative serum creatinine greater than 180  $\mu$ mol/l;
- creatinine between 150  $\mu$ mol/l - 180  $\mu$ mol/l with greater than 100 mL iodinated contrast usage during procedure;
- total iodinated contrast load used greater than 200 mL;
- allergy to iodinated contrast;
- performance of the EVR in the operating room (with a mobile image intensifier) as opposed to the angiography suite.

The DynaCT was assessed in a non-blinded manner by the operating surgeon at the procedure, in order to detect any technical problems with the endovascular repair. Angiograms and the DynaCT scans were subsequently reviewed by a vascular radiologist to determine if any technical problems were undiagnosed. Any technical problems that required intervention were immediately corrected. Postoperative assessment was with duplex and computed tomography (CT) scanning as outlined above.

The quality of the DynaCT was assessed after EVR. Multiplanar images were analyzed in a non-blinded fashion by a single consultant vascular radiologist (R.M.). A visual analogue score was devised to categorize the quality of the images obtained from the DynaCT software into four groups (excellent, good, adequate, and poor) based upon contrast opacification, resolution of images, and presence of movement artifact. A separate visual analog score was used to record the degree of confidence in using DynaCT to evaluate technical outcome of endograft deployment

**Table I.** Secondary procedures in the control group (within 30 days)

<i>Peri-procedural complications</i>	<i>No. patients (n = 14)*</i>	<i>Secondary procedures</i>	<i>No. procedures (n = 17)</i>
Type 1a endoleak	5	Extension cuffs and balloon	2
		Balloon exp. stents	3
Type 1b endoleak	2	Limb extensions	1
		Limb extensions and self-expand. stent	1
Iliac occlusion	2	Fem-fem crossover	2
		Thrombo-embolectomy	1 (failed)
		Self expand. stents	1 (failed)
Graft limb thrombosis	3	Thrombo-embolectomy	3
Femoral occlusion	1	Femoral endarterectomy	1
Limb kinking-stenosis	2	Self expand. stents	2

No., Number.

\*One patient required correction of both type 1a and 1b endoleaks.

(1-no confidence, 5-intermediate, 10-absolute confidence in interpretation).

**DynaCT scanning.** The angiographic suite was equipped with a ceiling-mounted C-arm angiography system (Siemens Medical, Berlin, Germany) with active matrix flat panel detector technology (30 × 40 cm) capable of digital fluoroscopy, subtraction/non-subtraction, and rotational angiography. Specialized software (DynaCT) was used to generate CT-like images from on-table rotational angiographic acquisitions with contrast resolution of 10 Hounsfield units (HUs).

A total of 48 mL of radiographic contrast (Visipaque 320 mg I/mL or Omnipaque 300 mg I/mL, GE Healthcare, Oslo, Norway) at 8 mL/second (96 mL of 50% diluted medium) was injected via a 4F pigtail catheter placed at the level of the highest renal ostium. Angiographic CT parameters, with respiration suspended, were a 0.8° increment, 512 matrix projection, 220° total angle, 20°/second, 20 frames/second with 248 projections. The time interval from C-arm rotation to automatic generation of images on the monitor was 122 seconds with an excursion time of 8 seconds (4 second delay). Image postprocessing with correction algorithms (ring correction, scatter correction, and truncation correction) was carried out to optimize image quality.

Multiplanar reconstructions were performed on a commercially-available workstation (Voxar 3D, Barco, Kortrijk, Belgium) with the images being presented as maximum intensity projection (MIP) images in the axial, sagittal, and coronal planes. The mean cumulative radiation dose was 123 mGy (dose area product [DAP] 3574.0 microGy/m<sup>2</sup>).

**Statistical analysis.** Comparison between the two cohorts was carried out using the  $\chi^2$  test (random ordinal variables), the Fisher exact test (non random variables) and the two-tailed *t* test (continuous variables) at the 5% level of significance.

## RESULTS

**Early reinterventions in the control group.** In the control group, 14 patients with 15 technical problems (4.5%, n = 14/312) required 17 reintervention procedures

within 30 days of initial EVR (10 endovascular and 7 surgical). The mean time interval between original surgery and secondary intervention was 7 days. Nine of these patients were symptomatic. Eight presented with acute limb ischemia with 6 patients presenting with symptoms prior to discharge (but before CT or duplex imaging). Two patients with acute limb ischemia presented after discharge from the hospital and within 30 days of their procedure. Pre-discharge computed tomographic angiography (CTA) and color flow duplex scans did not demonstrate any stent-related anomalies which might have predicted limb ischemia in these 2 patients: 1 required femoral endarterectomy and patch angioplasty for femoral artery occlusion and the other developed a thromboembolic occlusion of the graft limb. One further patient developed acute abdominal and lumbar pain as a result of a type 1a endoleak detected prior to undergoing pre-discharge imaging.

The remaining 5 asymptomatic patients all had demonstrable type I a/b endoleaks on pre-discharge surveillance detected by both CTA and color flow duplex scan (Table I).

Retrospective review of all notes and imaging in this cohort of 14 patients suggested that 86% of the technical problems (n = 12) were potentially identifiable and correctable with better intra-operative quality control (7 type 1a/b endoleaks in 6 patients and 6 limb kinking/stenosis/native vessel stenosis). Overall, 3.8% of the entire patient cohort had a potentially preventable early reintervention.

**Feasibility of DynaCT.** In the cohort of 80 consecutive patients who underwent elective EVAR following the introduction of the new protocol, DynaCT was feasible in 81.3% (n = 65/80). Of the 15 patients who did not satisfy the inclusion criteria for DynaCT, eight procedures were preferentially performed in a surgical theatre using a mobile C-arm image intensifier (Sirenmobile 2000-2; Siemens Medical, Berlin, Germany). Six of these patients underwent aortouniiliac graft (AUI) procedures requiring femoral to femoral cross-over bypass. Two additional patients with unsuitable femoral access vessels required fashioning of common iliac conduits. Five patients were excluded from the protocol because they exceeded the baseline creatinine threshold as defined by the protocol. One patient had proven iodinated contrast allergy, so this procedure was

**Table II.** Patients demographic and aneurysm morphology (multislice 64-CT assessment)

	Control group (n = 312)	DynaCT group (n = 80)
Age (years)	75 (range, 46-93)	73 (range, 41-91)
Male gender (%)	89.7%	92.3%
m-CPI fitness score	4.3	2.9
Aneurysm diameter	61 mm (range, 42-115)	63 mm (range, 52-99)
Aneurysm neck		
Length	20 mm (range, 4-90)	22 mm (range, 8-120)
Length <15 mm	24.1%	26.1%
Diameter	23 mm (range, 18-35)	24 mm (range, 20-34)
Diameter >30 mm	6.1%	9.2%
Angulation >60%	18.6%	20.0%
Thrombus >50%	7.7%	12.3%
Endografts		
Zenith Flex	—	62.5% (n = 50)
Zenith TFB	38.1% (n = 119)	23.8% (n = 19)
Zenith AUI	6.7% (n = 21)	2.5% (n = 2)
Talent	41.7% (n = 130)	11.2% (n = 9)
Talent AUI	8.0% (n = 25)	—
Excluder	5.4% (n = 17)	—

Continuous variables are expressed as mean.

CT, Computed tomography; m-CPI, modified customised probability index; TFB, Tri-Fab; AUI, aortouniiliac graft.

performed entirely by CO<sub>2</sub> digital subtraction angiography. A further patient required an urgent renal stent for an inadvertently covered renal artery and exceeded the intra-operative contrast load threshold as defined in the DynaCT protocol.

The quality of DynaCT imaging was graded as either good (n = 29) or excellent (n = 25) in the majority of cases (83.1%) with a confidence 6-10 in 96.9% of instances. In 2 patients (3.1%), the obtained qualities of images were considered poor due to a displaced catheter into the body of the endograft not allowing scrutiny of the proximal landing zone or renal vessels with adequate opacification. Both necessitated further acquisitions following manipulation of the pigtail catheter above the endograft which resulted in adequately graded quality images.

**Patient demographics, aneurysm morphology, and stent grafts – control vs DynaCT cohorts (Table II).** Patient demographics and preoperative CT evaluation of aneurysm morphology between the control and DynaCT groups were similar with no statistically significant differences evident for age, gender, and aneurysm morphology (neck diameter, length, angulation, and presence of endoluminal thrombus).

The modified Customized Probability Index (m-CPI) was used as a preoperative scoring system to estimate baseline fitness scores.<sup>11</sup> Baseline fitness scores were better in the DynaCT cohort compared with the control group which reflected the exclusion of patients with impaired renal function as per DynaCT protocol, but this difference did not reach statistical significance (2.9 vs 4.3  $P = .1$ ;  $t$  test).

**Table III.** Procedural data

	Control group	DynaCT group
Room occupancy		
Minutes	140	145
Screening time	24' 42"	24' 48"
Radiation dose		
DAP microGy/m <sup>2</sup>	13314.9	14808.9
CRD mGy	456	513
Contrast load		
mL	120	138
Medium		
Visipaque 320	69.2%	52.6%
CO <sub>2</sub> -DSA	8%	40%*

DAP, Dose-area product; CRD, cumulated radiation dose; CO<sub>2</sub>-DSA, carbon dioxide digital subtraction angiography.

All comparative values are statistically non significant unless denoted (\*) in table.

\* $P < .01$  ( $\chi^2$  test).

Commercial endografts deployed in the control group included bifurcated Zenith (Cook Medical, Bloomington, Ind) TFB (n = 119), AUI Zenith (n = 21), Talent (Medtronic, Santa Rosa, Calif) (n = 130), AUI Talent (n = 25), and Excluder Gore (Flagstaff, Ariz) (n = 17). In the DynaCT cohort, deployed endografts included bifurcated Zenith Flex (n = 50), bifurcated Zenith TFB (n = 19), AUI Zenith (n = 2), and Talent (n = 9).

In the control group, 116 technical problems which required adjunctive intra-operative procedures were detected by uniplanar completion angiography in 88 patients. This did not differ significantly compared with the 19 anomalies detected by initial completion angiography in 16 patients in the DynaCT group (88/312, 28.2% vs 16/80 20.0%,  $P = .14$ ,  $\chi^2$  test). All anomalies were immediately corrected to achieve technical success as defined by Society for Vascular Surgery (SVS) angiographic parameters alone.<sup>12</sup>

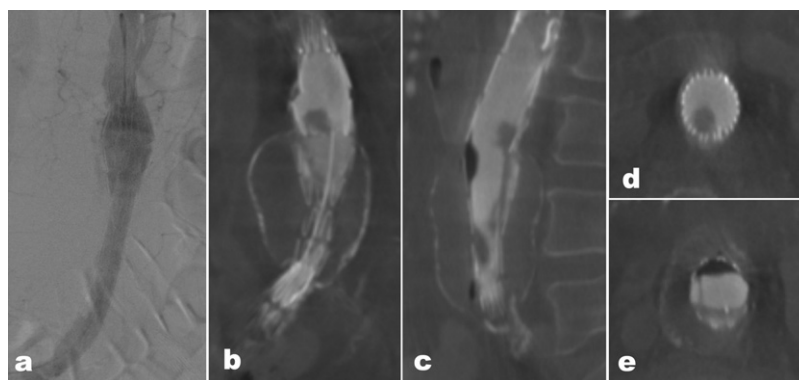
**Procedural data.** Total radiation exposure was increased when compared with the control group (14,809 vs 13,315 DAP/microGy/m<sup>2</sup>  $P = .1$ ,  $t$  test and 513 vs 456 cumulated radiation dose (CRD) mGy  $P = .1$ ,  $t$  test) but this was not significant. The use of CO<sub>2</sub> digital subtraction angiography was significantly higher in the DynaCT cohort compared with the control group (40% vs 8%  $P < .001$ ,  $\chi^2$  test) and this contributed to a negligible net increase in contrast use of 18 mLs after the DynaCT run (138 mL vs 120 mL) despite the net contrast load of 48 mL from the DynaCT alone (Table III).

**Intra-operative anomalies detected by DynaCT.** DynaCT detected five clinically significant anomalies (6.25%, 5/80) not seen at completion angiography. Each abnormality required on-table correction to ensure technical success. The technical problems included two anterior type 1a endoleaks each treated with balloon dilatation (Fig 1), one type 3 endoleak corrected by balloon angioplasty, a partial main graft thrombosis requiring balloon thromboembolectomy (Fig 2), and an iliac limb compression requiring a self-expandable nitinol stent (Luminex, Bard, Tempe,





**Fig 1.** An 80-year-old man with a 65 mm infrarenal abdominal aortic aneurysms (AAA) with a 28 mm diameter concentric calcified neck (>40%) underwent an endovascular repair (EVR) (bifurcated Zenith Flex). Final angiography (a) indicated apparent exclusion of the endoleak. Evaluation with DynaCT, sagittal (b) and axial (c) reconstructions, demonstrated a significant anterior type 1a endoleak. Further balloon dilatation of the aortic neck resulted in complete correction of this proximal leak at a second multiplanar angiographic computed tomography (CT) (d, e).



**Fig 2.** A 73-year-old woman with a 55 mm abdominal aortic aneurysms (AAA) and 35 mm right common iliac artery (CIA) aneurysm underwent endovascular aneurysm repair (EVAR) with an aorto-uni-iliac Zenith device (12F) in the angiographic suite. DynaCT multiplanar rendering in coronal (b) sagittal (c) and axial (d, e) planes, showed an acute thrombus within the main body of the graft which had not been previously detected by completion angiography (a). On-table graft-thrombectomy via the indwelling common femoral artery (CFA) sheaths was performed successfully.

Ariz). All adjunctive procedures were assessed with further DynaCT and found to be satisfactory.

All completion angiograms were reviewed independent of patient outcome. No patients with an angiogram considered satisfactory by the operating surgeon was subsequently found to have an abnormality that would have necessitated a further intervention or procedure. Similarly, all abnormalities identified by the operating surgeon on DynaCT were identified by the reader blinded to outcome.

**Comparative outcomes between control and DynaCT groups.** In the control group, the 30-day mortality was 3.8% (12/312). The mortality in the patients that required early reintervention in a secondary procedure was higher than those in whom no early reintervention was required (14.3%  $n = 2/14$  vs 3.3%  $n = 10/298$ ;  $P = .038$ ,  $\chi^2$  test).

Following introduction of the new protocol, the perioperative mortality in the DynaCT group was 2.5% (2/80). Most significantly, no patients had a technical problem,

identified by the standard pre-discharge surveillance that required reintervention within 30 days ( $P = .05$ ,  $\chi^2$  test).

The overall median length of stay was greater in the control group compared with patients undergoing DynaCT (6 days vs 4 days,  $P < .001$ ,  $t$  test). Length of stay was higher in those patients within the control group who had required a secondary adjunctive procedure (12 days vs 5 days,  $P < .001$ ,  $t$  test).

Baseline serum creatinine was comparable between the two groups and no significant rise in mean pre-discharge serum creatinine was detected between control and DynaCT groups (mean rise in creatinine of  $14.8 \mu\text{mol/L}$  vs  $15.6 \mu\text{mol/L}$ ;  $P = .4$ ,  $t$  test). No patient in the DynaCT required postoperative renal replacement therapy.

## DISCUSSION

The clinical success of endovascular aortic procedures is defined by the complete exclusion and decompression of the aneurysm sac without intra-procedural evidence of clinically relevant endoleaks or other graft-related complications (stent migration, kinking, stenosis or occlusion).<sup>12</sup> Analyses of trial and registry data have indicated a 30-day survival advantage for endovascular repair when compared to open surgery.<sup>13,14</sup> However, trial data have also demonstrated that the endovascular techniques were associated with a higher rate of early reintervention.<sup>2</sup>

Uniplanar completion angiography is one accepted modality for assessing the technical result of endograft insertion during the primary endovascular procedure. However, due to a significant false-negative rate, early duplex or CT scanning is advised to confirm technical success.<sup>5</sup> Data from the Dutch Randomized Endovascular Aneurysm Management (DREAM) study demonstrated an early vascular or endograft-related complication rate of up to 16%.<sup>14</sup> Similarly, the EVAR I trial demonstrated that 1 in 10 patients required early endovascular reintervention for procedural-related complications.<sup>15</sup> The risk of early reintervention may be higher in patients with hostile aortic morphology. Type I endoleaks have been reported in up to 11% of procedures with unfavorable aneurysm morphology, primarily neck angulations ( $>60^\circ$ ) and short neck length ( $<10 \text{ mm}$ ).<sup>16</sup>

The present study has demonstrated that 3.8% of patients undergoing EVR for AAA required early reintervention due to technical problems that were not identified by uniplanar completion angiography. Clearly these results suggest that a better method of intra-operative quality control is required to assess the technical success of EVR and direct immediate revisional strategy. Preventing early reintervention due to unidentified technical problems is crucial to improve perioperative mortality and to improve cost effectiveness. In the current study, the two type I endoleaks identified by DynaCT were anterior in location and this makes the point that angiography, if used for quality control, should probably be performed in at least two planes.

The availability of DynaCT in the angiography suite offers an immediate cross-sectional evaluation of the endo-

vascular procedure. Despite reported concerns regarding inadequate image quality using angiographic CT, the high contrast spatial resolution has been proven to be comparable to conventional CTA.<sup>17</sup> Previous isolated case reports have demonstrated that the use of intra-procedural DynaCT may be beneficial during cerebrovascular intervention, translumbar type II endoleak repair, neuro-endovascular procedures, and intra-arterial chemo-embolization.<sup>18-23</sup>

Eide et al reported the use of DynaCT to evaluate aortic aneurysms in 7 patients during elective EVR but did not determine the clinical applications.<sup>24</sup> In the present series of 80 patients, the introduction of a new evaluation protocol following EVAR demonstrated that an additional 6.25% ( $n = 5/80$ ) of patients benefited from immediate correction of DynaCT-detected endograft-related complications. This prevented the need of any further secondary procedure within 30-days and was associated with a significant reduction in hospital stay.

The multi-planar rendering of the acquired high-contrast resolution images allowed for a combined reconstruction of stent-graft and soft tissue visualization.

The quality of images obtained by DynaCT was high, with the presence or absence of endoleaks being decided with a high degree of confidence. Confounding factors influencing endoleak detection using DynaCT included the extensive presence of mural calcification and metal beam artifact. Scrutiny of the images in the axial, sagittal, and coronal planes, however, removed most of the diagnostic uncertainty.

DynaCT evaluation required an additional iodinated contrast load of 48 mL amounting to a mean contrast load of 138 mL. This contrast load was not significantly different to that used in the control group, and was not associated with any additional determinable effect upon renal function. The total procedural contrast usage in the present study was below the nephrotoxic threshold of 5 mL of contrast/kg body weight/serum creatinine ( $\text{mg/dL}$ ).<sup>25</sup> Greenberg et al have previously demonstrated that perioperative renal function was not compromised by procedural iodinated contrast loads of up to 156-162 mL.<sup>26</sup> A further disadvantage of DynaCT is the increased radiation dose to the patient. In the present investigation, the use of DynaCT was associated with an increased radiation exposure of 57 mGy, which would appear to be relatively insignificant in the context of endovascular repair and subsequent follow-up.

Reported strategies to minimize iodinated contrast loads during EVR include gadolinium-based agents which are expensive and hyperosmolar and may even be nephrotoxic in the dosages required for EVAR,<sup>27</sup> and the use of  $\text{CO}_2$ -DSA supplementation, which was the strategy employed in the current investigation. Chao et al have previously reported that  $\text{CO}_2$ -DSA supplementation in EVAR patients with renal insufficiency may permit a significant reduction of iodinated contrast.<sup>28</sup> This is in keeping with the findings in this investigation, where the increased usage of adjunctive  $\text{CO}_2$ -DSA in the DynaCT cohort (40%,  $n = 32$ ) superficially appeared to have reduced contrast loads by up to 25% in the primary procedure, up to DynaCT evalu-

ation. This CO<sub>2</sub>-DSA supplementation facilitated management of the contrast load so that even with the addition of DynaCT, the latter cohort exhibited a non significant increase of total iodinated load of only 18 mL.

This additional iodinated contrast volume is comparable to the additional 20 mL load that would normally have been administered to the patient should biplanar completion angiography had been performed. DynaCT, however, provided additional higher resolution imaging and with the possibility of multiplanar rendering. The current limitations of DynaCT relate primarily to the dimensions of the flat panel which provides a craniocaudal extent of the scan of approximately 30 cm which may not be adequate to visualize extensive endovascular repairs on a single rotational acquisition.

There are a number of significant limitations to the present study. The investigation was not randomized and, therefore, any observations regarding hospital stay and mortality rates may be due to increased experience rather than to an improved quality-control protocol. The DynaCT group was compared to a historical group where uniplanar angiography was used as the primary method of quality control. It might be argued that uniplanar angiography is not an effective method of assessing EVR and that biplanar angiography should be used. The present investigation would support the assertion that uniplanar angiography is inadequate for effective quality control but this methodology appears to be in widespread use. DynaCT would appear to offer some significant theoretical advantages to biplanar angiography, with the ability of DynaCT to visualize the endograft, aneurysm sac, and soft tissues in three projections using appropriate windowing.

DynaCT is a feasible, reproducible, intra-procedural technique, applicable to the majority of patients undergoing endovascular aortic aneurysm repair, which aids the immediate correction of graft-related anomalies and minimizes the need for early secondary interventions. This might result in improved patient outcomes and may have a significant bearing on the necessity of CTA in the postoperative period.

Perhaps the most significant finding of the present study has been to demonstrate that uniplanar angiography alone is inadequate to assess the technical result of endovascular aneurysm repair. DynaCT has demonstrated that nearly 4% of patients had an unidentified, but correctable, technical error not diagnosed by uniplanar angiography. While we have adopted DynaCT as a method of quality control in our unit, we realize that this will not be available to all practitioners. In the absence of intra-operative cross-sectional imaging, we would suggest that the assessment of the technical adequacy of endovascular aneurysm repair should encompass more than a uniplanar angiogram. Biplanar angiography would identify many of the anterior endoleaks described in this study and further work will clarify whether biplanar angiography gives similar information to DynaCT.

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## AUTHOR CONTRIBUTIONS

Conception and design: LB, RM, IL, MT  
Analysis and interpretation: LB, TA, LR, RM, IL, MT  
Data collection: LB  
Writing the article: LB, TA, RM, MT  
Critical revision of the article: RM, IL, MT  
Final approval of the article: LB, TA, RM, MT  
Statistical analysis: LB, TA, MT  
Obtained funding: Not applicable  
Overall responsibility: LB, TA, MT

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